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Continuous Wave Radar and THE MID-AIR COLLISION PROBLEM*

by J. Q. BRANTLEY, JR.

Prevention of collisions between airplanes in flight constitutes one of the air transportation industry's most acute growing pains. Between 1946 and 1952, airline airplanes were involved in twelve mid-air collisions. Of these accidents, three were airline-to-airline, eight were airline-to-nonairline, and one was airline-to-military.

In addition to fatal collisions, hundreds of near-misses are reported each year. Numerous others go unrecorded.

The most disastrous mid-air collision in aviation's history occurred on November 1, 1949 in Washington, D. C. This accident involved an airline DC-4 and a Lockheed P-38 (military) both on final approach to the same runway. The P-38 struck the DC-4 just aft of the passenger cabin and its propellers completely severed the tail of the larger aircraft. In the ensuing crash, 55 people lost their lives.

NEAR DISASTER

On August 26, 1953, a spectacular airline collision occurred near Chicago when a Convair 240 carrying 24 passengers and a Convair 340 carrying 27 passengers brushed each other at 10,500 feet. The planes had taken off from Chicago Midway Airport one minute apart and both were cleared to a cruising altitude of 11,000 feet, but to different destinations. Apparently the CV-240 was in level flight and was struck from beneath by the still-climbing CV-340. Fortunately, damage to the planes was slight and both were able to make safe landings. What could have been total destruction was averted by only a few inches.

One approach to the collision problem embodies the use of some form of airborne radar to provide recognition of collision threats in advance. This article discusses the required conditions for prior recognition of such threats and examines the capabilities of pulse and continuous wave radars in this application.

One can go a long way toward understanding collision recognition and avoidance by analyzing how the driver of an automobile avoids collisions. The driver determines an approaching automobile's present position visually; notes its motion and the change in its position relative to himself; and mentally estimates its future path. If the estimated future position of the approaching vehicle is identical to his own estimated future position, then he slows, stops, or turns. In short, the driver looks, evaluates, and acts if necessary. Determination of "present position" involves distance (range) and angular position (closure angle) while estimation of "future position" necessitates a knowledge of the speed of approach (closure rate) and the rate-of-change of closure angle.

DANGER PRESENT

The behavior of closure rates and closure angles of two converging aircraft is related to the collision potential present. It is a well known fact that an approaching plane whose closure angle remains constant is on a collision course and that the more slowly the angle changes the closer the approach to a collision course. Parallel statements can be made concerning closure rate: a constant rate is a definite collision indication, and the more slowly it varies, the closer the approach to collision conditions. For example, refer to the cases shown in Figures 1 and 2. As the airplanes approach the collision point, the closure angle θ and the closure rate remain constant. In the near-miss case shown in Figure 2, the range does not decrease uniformly; the closure angle increases as the planes converge; and plane A arrives at the course intersection

**The work described was carried out under the Laboratory's internal research program. The article represents a condensed and somewhat modified version of an article that appeared in the June 1953 issue of SKYWAYS.*

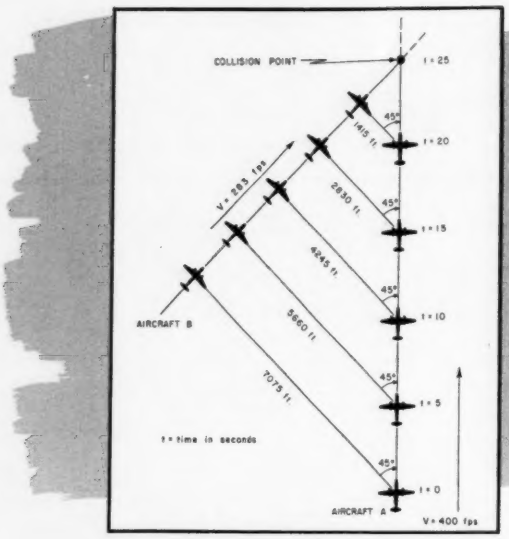


Figure 1: Two aircraft at identical altitudes converging and on collision courses. Note the constant closure angles and closure rate.

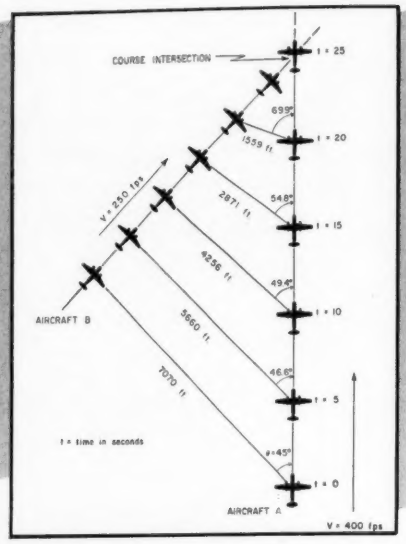


Figure 2: Two aircraft at identical altitudes flying near-miss courses. Note the changing closure angles and closure rate.

before B. The greater the miss-distance the larger the rate-of-change of θ and the rate-of-change of closure rate.

In these examples, straight-line flight at constant speeds was used. The conditions stated also hold for curved paths and varying speeds, but in this case, while **sufficient,** they are not **necessary.** A collision could occur even though a prior history of rapidly varying closure rate (or angle) had prevailed. But, since the greater portion of airline operating time is spent in essentially straight-line flight, the constant closure rate and constant closure angle conditions can serve as useful tools for prior recognition of collision threats.

In practice, a means must be provided whereby several aircraft may be observed and the most dangerous one singled out. In this respect, the concept of closure time is useful. Closure time is the ratio of range to closure rate, and is defined as the time it would take an aircraft to "arrive" if it were to continue its approach at a constant closure rate. For example: a plane ten miles away (range) approaching at ten miles a minute (closure rate) would arrive in one minute (closure time).

Figure 3 demonstrates how closure time can be used for target discrimination. The closure time of A (closing on C) is twelve seconds and the closure time of B (also closing on C) is thirty-six seconds. We can therefore conclude that the closest target is not necessarily the most dangerous since A will be the first to arrive.

Closure time is the true yardstick for target discrimination.

Extensive tests have indicated that ordinary search radars are unsuitable for mid-air collision prevention, for the following reasons:

a) Primarily because of large ground echoes which tend to mask weaker aircraft echoes, it is difficult to detect aircraft on a radar "position" scope

b) The requirement for constant surveillance of the radar scope would be unrealistic even if aircraft echoes were discernible

THE COVER

The photo-insert appearing at the left, as well as at the top of the cover page, shows the sound field produced in a turbulent jet stream.

With the advent of the jet airplane, aircraft noise has become an increasingly serious problem and one which must probably be resolved before jet aircraft can expect to find wide commercial use. One logical approach to establishing methods for effectively silencing jet engines is to arrive at a detailed understanding of the manner in which sound is generated. The cover photograph clearly shows how sound waves are formed in a turbulent jet stream (heavy white region in photograph) moving at about 1,000 miles per hour. A close inspection of the picture will indicate that the origin of the noise is not at the exit of the jet as might be expected, but further downstream at a point where the circular, sound-wave pattern can be detected spreading out in two directions. As may be noted, the sound field created by a high-velocity, turbulent jet stream bears a marked resemblance to the wave patterns that result when stones are cast into a still pool, and in many ways the two types of wave phenomena are similar. This photograph was taken with an extremely sensitive optical (schlieren) system that permitted the motion of the jet stream to be frozen at a millionth of a second.

c) Estimation of future position is relatively difficult and uncertain from a presentation of present position

d) Extraction of a target's closure rate from a pulse radar, while possible, requires complicated techniques

All of these things tend to minimize the effectiveness of pulse radar for collision warning.

RADAR FOR COLLISION WARNING

There exists another branch on the radar family tree known as continuous wave or cw radar which merits evaluation. As its name implies, cw radar transmits energy continuously, pulse radar emits energy in bursts. Both, however, determine range by measuring the length of time it takes transmitted energy to travel to a target and return. The manner in which the delay time is measured constitutes one of the primary differences between the two.

The most important single aspect of cw radar is its ability to measure closure rates accurately and rapidly by use of the doppler effect. The doppler phenomenon appears in the form of apparent carrier frequency changes in radar echoes from moving targets. When detected in the radar receiver, the frequency of energy thus reflected differs from the frequency at transmission by an amount which is accurately proportional to the closure rate of the target. By measuring this difference one can determine a target's closure rate. To do this with a cw radar it is only necessary to compare the frequency of the received signal with that of the transmitter; to do so with a pulsed radar is considerably more difficult.

Closure angles are generally measured by special antenna configurations. Such systems are complex if large regions are to be searched and complications result from airframe space limitations. Further, if high angular resolution is desired, antenna physical dimensions are large. For practical reasons, therefore, it is necessary, at least at present, to restrict measurement of closure angles to rough approximations, and to rely on these measurements primarily for determining the appropriate turn direction for avoidance of an impending collision. The future development of improved techniques for angle measurement may make possible the use of the constant angle criterion for prior collision recognition.

A radar system's maximum range capabilities at low altitudes are enhanced by an ability to categorize targets by their closure rates. Figures 4 and 5 on the following page illustrate how a "search by closure rate" system is superior to a "search by range" system for detecting moving targets. In Figure 4, echoes from the ground are shown to be received from a wide spectrum of ranges. These echoes tend to smother reflections from other aircraft. In Figure 5, however, ground echoes are clustered about the radar-carrying aircraft's ground speed of 300 mph and the target's closure rate of 600 mph places its echo beyond the ground return. Effective elimination of ground clutter, thus achieved, permits detection of aircraft at ranges exceeding those obtainable through ordinary search by range systems.

For closure rates which place aircraft echoes in the ground clutter, a loss in maximum range results. This condition is not as serious as one might at first suppose, since for lower approach rates early detection is not as imperative as for higher rates.

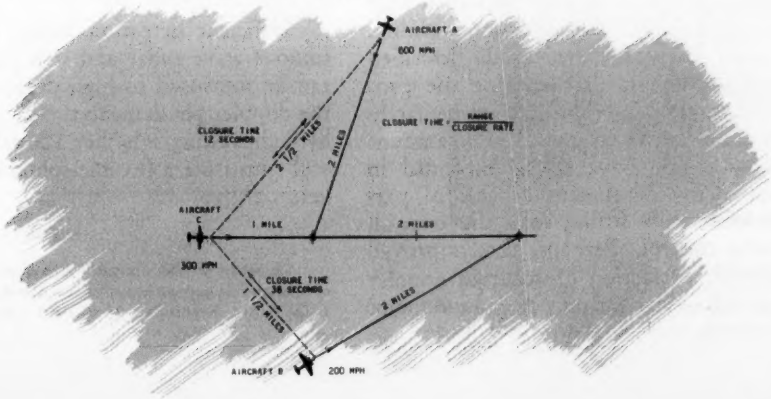
For high-speed targets, such as that shown in the illustration, the search by closure rate method is at its best.

EASING THE PILOT'S TASK

To reduce the pilot's work load and to relieve him of the necessity for watching the radar output continuously, a combination radar-computer type system is desirable. Evaluation of the collision potential would then be accomplished automatically by accurate measurement of closure rate, deviation of closure rate, and accurate observations of closure angle deviation if technically feasible. The appropriate data and decisions of the computer would then be displayed in the cockpit by means of a suitable indicating device. Continuous wave radar, by virtue of its compatability with computing devices, is suited for this type of application.

To assess the capabilities of a continuous wave radar, ground tests were conducted at the Cornell Aeronautical Laboratory using the 1500 megacycle AN/APG-17

Figure 3: Hypothetical case of "double" collision threat demonstrating that the closest plane is not necessarily the most dangerous.



radar. The transmitter output power of this radar is approximately one watt and it employs an antenna system having horizontal and vertical beamwidths of approximately 66° and 74°, respectively. Separate antennas are used for the transmitter and receiver.

With the radar operating as a pure cw system (measuring speed only), twin-engine aircraft such as the DC-3 and Convair 240 were detected at ranges up to two and one-half miles. Private aircraft normally gave good echoes at ranges slightly greater than one mile. Because these results were obtained under ideal conditions with none of the problems common to airborne installations, more transmitter power and increased antenna gain would be required to achieve adequate ranges in flight.

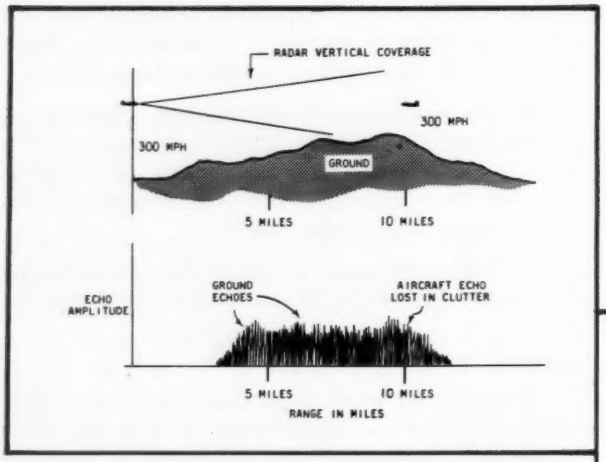


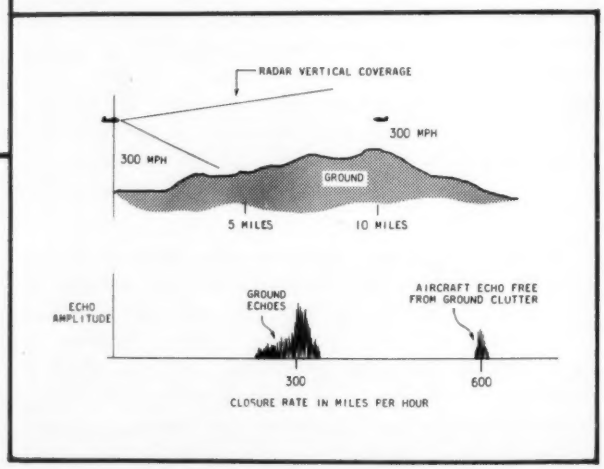
Figure 4: "Search by range" method employed by most pulse radars. Aircraft echoes are smothered by ground clutter.

Computing circuits to perform the necessary collision warning functions were constructed and tested and no great difficulties were encountered.

From what has been said, it might be assumed that cw radar is immediately available for collision warning. This is not the case. Even if the methods described should prove their usefulness, they are for the projected future and cannot be instrumented immediately from on-the-shelf components. A considerable amount of time and energy would have to be expended in developing a trustworthy instrument capable of performing its task well while fitting into the over-all pattern of air traffic control. Perhaps, also, improved techniques will permit extraction of accurate doppler information from pulse-type radars. A pulse-doppler system capable of finding bad weather areas, serving as a terrain avoidance instrument, and capable of preventing mid-air collisions, while retaining a reasonable degree of simplicity, could well constitute the optimum solution to the collision problem.

The assumption has been made that the ultimate solution to this problem will be a self-sufficient system. While this is not necessarily the case, there are reasons why a self-sufficient system seems desirable. Among these reasons are: freedom from dependence upon ground facilities, freedom from dependence upon equipment carried in other aircraft, and the flexibility of operation which such a system would allow. A natural witness in defense of the self-contained system is the common bat, who has his own sonic radar and whose "collision prevention" abilities are extraordinary. If we could provide our aircraft with radar comparable in performance to his, but on a much larger scale, we would no longer be concerned with mid-air collisions.

Figure 5: "Search by closure rate" method employed by continuous wave radar. Echoes from high-speed aircraft are not masked by ground clutter.



Sufficient detection ranges are possible with continuous wave radar and it is known that closure rates can be measured to high degrees of accuracy by using the doppler phenomenon. It remains to be determined, by flight testing, whether a suitably engineered cw radar will constitute a feasible solution to the collision problem.

REPORTS

"A study of the aircraft collision problem with particular emphasis on the possible application of continuous wave radar techniques," Brantley, J. Q., C.A.L. Report No. JA-774-P-1 (September 1952).

New Developments in HIGH TEMPERATURE STRAIN GAGES*

by JAMES E. CARPENTER

The advent of the supersonic age has brought with it a pressing demand for improved methods of statically testing structural components of aircraft and missiles. The need for new techniques stems primarily from the excessively high temperatures associated with supersonic flight. At such speeds, structural components may be subjected to skin-friction temperatures higher than the softening point of aluminum, and portions of turbojet motors, which until now have operated at relatively low temperatures, may be forced to operate above the usable temperature limits of stainless steel. These severe temperature conditions drastically reduce the strength of materials, and the nonuniform temperature distributions that usually occur at such elevated temperatures produce thermal stresses that may exceed the normal operating stresses.

In response to this need, the Cornell Aeronautical Laboratory has undertaken several investigations aimed at developing new methods of testing materials and structures at elevated temperatures, and at devising the necessary, specialized instrumentation. A program is now in progress that seeks to develop a wire resistance strain gage for use at elevated temperatures.

The wire resistance strain gage plays a primary role in the field of experimental stress analysis. In essence, this type of gage is a short length of fine wire held in intimate contact with the material under test so that any strain or deformation suffered by the material is transmitted to the wire. A known relation between strain and the electrical resistance of the wire conductor permits a direct measurement of this strain by simply instrumenting the gage so that minute changes in gage resistance can be detected. Because such a device has many desirable characteristics, it is obviously worth while to perfect its application under more severe temperature conditions than it can withstand at present.

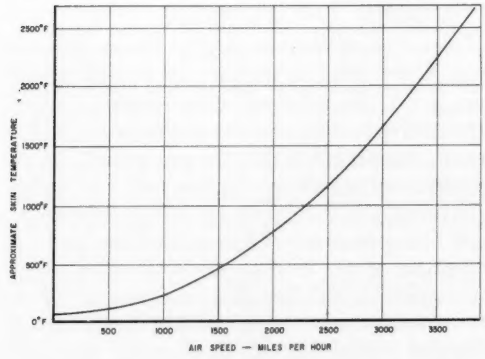
What are the high-temperature limitations of available wire resistance strain gages and why do these limits exist?

For continuous and reliable use of present gages, the test temperature must not exceed approximately 300°F. Some work has been reported where, for short periods of time, strain data believed to be reliable have been obtained up to 500°F, but completely adequate confirmation of such data is lacking.

When the temperature exceeds 300°F, virtually complete malfunctioning of the gage results. The major elements affected are the strain-sensitive wire and the bonding cement. Two types of cement are generally used for forming the gage and for bonding it to the material under test. Nitro-cellulose cement is commonly used for tests at or near room temperature and phenol-resin thermosetting cement may be used up to 300°F. Above this temperature, the phenol-resin cement loses its ability to transfer strain from the stressed member to the embedded strain gage wire.

The electrical resistance of the strain wire is affected by temperature differentials as much as, or more than, by strain differentials. Consequently, even for tests

**The work covered in this artcle was carried out under the jurisdiction of the Oak Ridge National Laboratory, Oak Ridge, Tennessee. Work was performed under a subcontract with the Union Carbide and Carbon Corporation, prime contractor to the Atomic Energy Commission.*



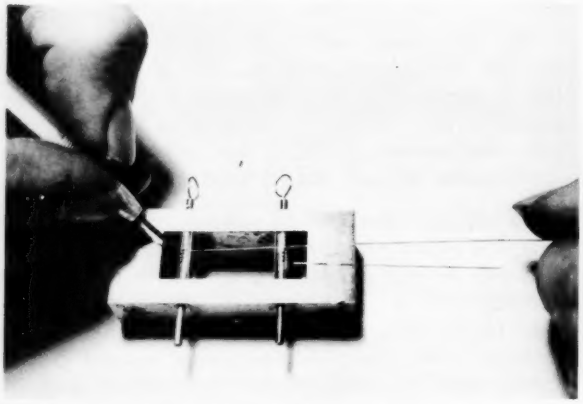
The above curve indicates how the skin temperatures of aircraft rise sharply as flight speed is increased.

Engineer Howard Wolko is determining the sensitivity of a C.A.L. strain gage by comparing the gage signal at various test temperatures with readings obtained simultaneously by means of an optical strain reader.

conducted at room temperature, extreme care is taken to minimize and compensate for temperature changes occurring during the course of a test. The temperature problem is complicated further because those few wires that are adequately strain sensitive, and are, at the same time, relatively insensitive to temperature change, are insensitive only over a rather limited temperature range. As a result of considerable research and development work, however, it has been possible to adjust this range to conform to the well-established temperature limits of the bonding cements.

MODEST APPROACH

The problems encountered in extending the high-temperature limit of gage operation make it improbable that an all-purpose, high-temperature strain gage will be developed in the near future. It is logical, therefore, to adopt the more modest approach of attempting to develop a gage to satisfy a specific set of conditions.



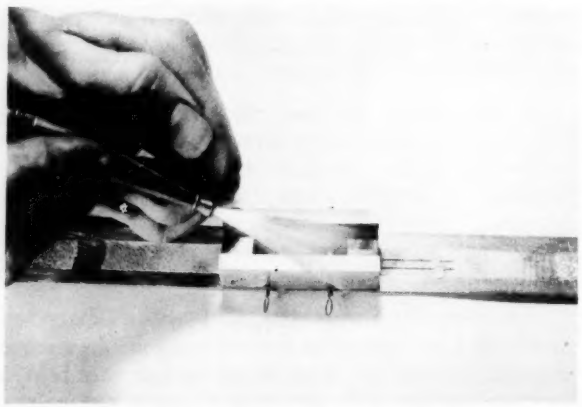
A grid-type strain gage being formed on the winding jig. Note the size of the strain sensitive wire compared with the human hand.

Accordingly, a program has been undertaken at the Cornell Aeronautical Laboratory to develop two particular types of wire resistance strain gages: one to operate at extreme temperatures for several days, and the other to operate in a highly radioactive field at moderately elevated temperatures for several months. Security regulations prohibit a detailed discussion of some phases of this study, as well as the specific mention of the magnitudes of temperature and time. Nevertheless, enough can be said of the difficulties encountered to provide an insight into the program.

Successful completion was dependent, of course, on finding the best combination of cement and wire. Because the relative merits of different wires and cements can be determined only after they are integrated into a gage, the initial effort on this program was devoted to developing a suitable technique for gage construction. No attempt was made to develop a prefabricated gage, similar to the standard commercially available type, inasmuch as that would have been a major problem in itself. The practice at the Cornell Aeronautical Laboratory was to construct the gage directly on the test sample. The techniques developed to do so were common to both types of gages under development.

One of the most difficult operations in the gage-construction procedure is the handling of the wire. Past experience has shown that the strain-sensitive wire should be approximately 0.001 inch in diameter. Since approximately four strands of this fine wire would be needed to equal the cross-sectional area of a human hair, it can be seen that gage construction on a laboratory basis requires great manual dexterity. The wire is formed into various grid shapes, depending on the length of the gage desired, and then short lengths of larger diameter wire are attached to the ends of the strain-sensitive wire to make possible the electrical connections to the strain-measuring equipment. Normally this joining of the two wires is accomplished by spotwelding, but previous strain gage experience at extreme temperatures has disclosed this spotwelded

The winding jig, still retaining the gage grid, has been inverted on the test sample so that the strain-sensitive wire is in contact with the surface of the specimen. The cement bonding the grid to the test sample is being sprayed through the opening in the jig.



union to be a weakness in the gage. To avoid this potential source of trouble, the lead wires used were 0.010-inch-diameter tubes having an inside diameter of about 0.003 inch. The joint was made by inserting the 0.001-diameter wire in the tube and then crimping the tube tightly around the strain wire.

ATTACKING THE PROBLEM

Once the techniques of gage fabrication were mastered, it was possible to start an evaluation of various gages under the required temperature conditions. Experimental procedures were established which were, in general, compatible with both gage evaluation programs. Temperature sensitivity characteristics were determined by maintaining a dummy, or bridge-balancing, gage at room temperature. This procedure permitted the evaluation of the various strain-sensitive wires insofar as temperature stability alone was concerned. Once the best wires were selected, an evaluation of the strain detection capabilities of these wires was undertaken. For this evaluation, temperature compensation circuits were employed in which the dummy gage, identical insofar as possible with the active gage, was bonded to

an unstrained sample of the same material as the test specimen. This dummy gage was so located that it was exposed to the same temperature and temperature differentials as the active strain-measuring gage.

GOAL ACHIEVED

The initial hurdle in the development of the gage for use at extreme temperatures was to find a wire-cement combination that would satisfy the time and temperature specifications. Approximately 50 gages, constructed of various wire-cement combinations, were investigated and their stability, temperature sensitivity, and life were determined. One wire and two cements were found potentially capable of satisfying this phase of the program requirements. Unfortunately, the only 0.001-inch wire under investigation which did not corrode and fail in less than a few hours at the test temperature was the platinum-iridium wire, which is also by far the most sensitive to temperature changes. The strain detection characteristics of the platinum-iridium gage were determined under extreme temperature conditions. The test results obtained from investigating approximately 50 gages indicate that strain measurement accuracies of the order of $\pm$ 3% are possible throughout the temperature range. The effect of time at temperature on the gage characteristics was also investigated.

Although the cements acceptable for the extreme temperature gage were found to be equally applicable to the moderate temperature gage, the platinum-iridium wire was not similarly useful because of its temperature sensitivity. Consequently, the major problem in constructing the latter gage was the selection of a strain-sensitive wire which would be reasonably unaffected by any change in temperature. Approximately 50 gages, constructed of various wire-cement combinations, were tested to determine and evaluate the temperature stability of several strain sensitive wires. As a result of this investigation, a particular nickel-chrome alloy wire was selected as the most promising. It was found possible to temperature compensate gages fabricated with this wire so that a temperature change as large as 10°F produced a bridge unbalance equivalent to strain of only 0.000005 in./in. The strain detection characteristics of the gage for use at moderate temperatures were determined. The test results obtained from investigating approximately 50 gages indicate that strain measurement accuracies of the order of $\pm$ 2% are possible throughout the temperature range.

GROUND WORK FOR THE FUTURE

On the basis of the work performed during this program, it appears possible under laboratory conditions to construct and control strain gages that are capable of satisfying the investigated temperature-time conditions. What is more important, the ground work may well have been laid for important future developments in the field of high-temperature instrumentation.

REPORTS

"Proposed future investigations of high temperature wire resistance strain gages," Carpenter, J. E., C.A.L. Report No. IG-886-S-1 (August 1953).

"Final report on development of a high temperature strain gage," Wolko, H. S. and Carpenter, J. E., C.A.L. Report No. IG-800-S-11 (December 1953).

About the Authors...

JAMES Q. BRANTLEY, JR. Two fortuitous and completely unrelated incidents are largely responsible for Dr. Brantley's deep interest in the mid-air collision problem. In 1946 while serving with the Navy at Corpus Christi, Texas, he witnessed a spectacular mid-air collision at night between two Navy seaplanes. The excitement and confusion of crash boats and searchlights that followed the explosion of the two airplanes in the night sky left an impression not readily forgotten. Three years later Cornell University awarded Dr. Brantley the Republic Aviation Corporation fellowship and admitted him to the Graduate School as a candidate for the Doctor's degree in Electrical Engineering. This fellowship, which the Laboratory supports at the University in the name of Republic, one of its sponsoring companies, stipulates that the holder perform his graduate work in electrical engineering in a field of potential benefit to the aircraft industry. This stipulation, and the still remembered crash of the two Navy seaplanes, shaped Dr. Brantley's decision to explore the potentialities of radar for the prevention of mid-air collisions.

Dr. Brantley obtained his Master's degree in Electrical Engineering from Cornell University in 1950 and his Doctor's in 1952. He received his Bachelor's degree in the same field from the University of Florida in 1949. Since 1952 he has been employed as an Associate Research Electronics Engineer in the Laboratory's Tactical Air Group. He is a member of Sigma Xi and Phi Eta Sigma, an undergraduate honorary society. He has published several articles on radar and the aircraft collision problem and in 1951, and again in 1952, presented papers on this subject at Air Safety Seminars held in Bermuda under the sponsorship of the Flight Safety Foundation.

JAMES E. CARPENTER. Mr. Carpenter has been closely associated with the Laboratory's strain gage development program since its beginning in 1948. He is currently Head of the Structural Laboratory Section of the Aero-Mechanics Department. Strain gage research is only one of this Section's many activities. Two other major areas of effort include an experimental investigation of the structural and vibrational characteristics of supersonic propellers and a program involving the structural evaluation of missiles and missile components.

Mr. Carpenter has published several articles concerned with the measurement of static strains at elevated temperatures and has presented a paper on this general subject before a national meeting of the Society for Experimental Stress Analysis. He has also conducted seminars dealing with high-temperature strain gages at the Oak Ridge National Laboratory.

He received his Bachelor's degree in Civil Engineering from Syracuse University in 1943 and his Master's degree in Mechanical Engineering from the University of Buffalo in 1951. Early in World War II, he was a structural test engineer at the Curtiss-Wright Research Laboratory, the forerunner of this Laboratory. During the war he was an officer in the United States Navy, serving with the "Seabees" in the Asiatic-Pacific Theater. He saw service both as a personnel officer with a construction battalion on Okinawa and as an executive officer with a batallion maintenance unit on Guam.

He is a member of the Society for Experimental Stress Analysis, Sigma Xi, Tau Beta Pi and Theta Tau.

Recent C. A. L. PUBLICATIONS

Requests for copies of the following unclassified reports should be directed to the Editor

"DETERMINATION OF THE EXTERNAL CONTOUR OF A BODY OF REVOLUTION WITH A CENTRAL DUCT SO AS TO GIVE MINIMUM DRAG IN SUPERSONIC FLOW, WITH VARIOUS PERIMETRAL CONDITIONS IMPOSED UPON THE MISSILE GEOMETRY," Ferrari, C., C.A.L. Report No. AF-814-A-1 (March 1953)

Formulae and processes are presented for determining the best shape for the external surface of an annular duct in order to produce a minimum amount of wave drag in supersonic flow under conditions which are invoked in order to ensure that the missile geometry will obey practical design requirements.

"DEVELOPMENT OF FOAMED CORE MATERIAL FOR RADOMES," Wahl, N. E.; Campagna, P. J. and Preston, H. M., C.A.L. Report No. UM-691-M-15 (August 1953)

The development of a foamed-in-place core material for high-speed aircraft or missile radome construction is described.

"INTEGRAL RELATIONS IN THE LINEARIZED THEORY OF WING-BODY INTERFERENCE," Flax, A. H., *Journal of the Aeronautical Sciences* (July 1953)

The results of this paper are arrived at by an extension of the reverse-flow theorems for lifting wings to the case of wings mounted on a cylindrical body.

"INTERACTION OF A PLANE FLAME FRONT WITH A PLANE SINUSOIDAL SHEAR WAVE," Markstein, G. H., *Journal of the Aeronautical Sciences* (August 1953)

As a first step towards treating the problem of interaction between flame and turbulence, the steady-state response of a plane flame front to a shear wave is analyzed.

"LOW RANGE AIR SPEED INDICATOR FOR HELICOPTERS," McMahon, E. P. and Pulley, A. L., C.A.L. Report No. IH-758-F-1 (September 1952)

A description is presented of an airborne instrument designed for the purpose of measuring relative air speeds of helicopters in low speed and hovering flight and presenting both longitudinal and lateral components of that velocity on pilot's instruments and on a recording oscillograph.

"RECOMMENDED UNITS, TERMINOLOGY AND TEMPERATURE MEASURING TECHNIQUES FOR ELECTRONIC EQUIPMENT," Pleuthner, R. L. and Welsh, J. J., *Ohio State University Report* (June 1953)

Recommendations are made for standardizing the presentation and correlation of heat transfer data with the aim of making such data of greater practical value to the electronics engineer.

"SAMPLING AND ANALYSIS OF COMBUSTION GASES," Beal, J. L. and Grey, J. T., *Journal of the American Rocket Society* (May-June 1953)

Rapid cooling of combustion gas samples in order to "freeze" the high temperature composition is discussed and methods for analyzing combustion gases are reviewed with particular emphasis on such newer methods as mass spectroscopy, infrared and ultraviolet absorption spectroscopy.

"SCHLIEREN PHOTOGRAPHS OF SOUND FIELDS," Schwartz, D. S. and Russo, A. L., *Journal of Applied Physics* (August 1953)

Schlieren photographs were taken of the sound field of both supersonic and subsonic jets over a range of Mach numbers from 0.7 to Mach numbers in excess of 1.0 in an effort to shed light on the manner in which sound is generated in turbulent jet streams.

"STABILITY OF FLOW IN AIR-INDUCTION SYSTEMS FOR BOUNDARY-LAYER SUCTION," Flax, A. H.; Treanor, C. E. and Curtis, J. T., C.A.L. Report No. AF-748-A (May 1953)

Theoretical and experimental studies of elementary air-induction systems for boundary-layer suction are discussed in this report.

"STRENGTH OF JOINTS IN TITANIUM BRAZED WITH SEVERAL ALLOYS," Smith, L. W. and Yerkovich, L. A., *Product Engineering* (July 1953)

Brazing techniques for joining sheet and bar titanium were investigated in an effort to obtain optimum joint strength properties.

"SUMMARY REPORT ON DEVELOPMENT OF LEAN-ALLOY CHROMIUM-NICKEL STAINLESS STEELS FOR HIGH TEMPERATURE USE," Salvaggi, J. and Guarnieri, G. J., C.A.L. Report No. KA-797-M-7 (June 1953)

Additions of titanium, boron, vanadium, molybdenum and carbon to 18-8 steels were studied at 1200°F. and 1500°F.

"THE AERODYNAMIC CHARACTERISTICS OF LOW-ASPECT-RATIO, WING-BODY COMBINATIONS IN STEADY FLOW," Lawrence, H. R., *Journal of the Aeronautical Sciences* (August 1953)

This paper gives a method for calculating the symmetric lift distribution on a configuration consisting of a wing with straight trailing edge and arbitrary twist mounted on an infinite circular cylinder at arbitrary angle of attack in steady uniform linearized incompressible flow.

"THE UPWASH CORRECTION FOR AN OSCILLATING WING IN A WIND TUNNEL," Goodman, T. R., *Journal of the Aeronautical Sciences* (June 1953)

The upwash correction is calculated for an oscillating three-dimensional wing in a circular wind tunnel at incompressible speeds.

"VOLTAGE AMPLIFIERS IN CONTROL CIRCUITS," Ives, R. L., *Radio Electronics* (April 1953)

This circuit is an adaption of a voltage multiplier principle to control circuits so that a reasonably high DC output can be obtained from filament circuits of ordinary electronic equipment at low cost and high dependability.

"VORTEX FREE-AIR THERMOMETER," Packer, L. S. and Box, H. C., C.A.L. Report No. IH-775-P-2 (April 1953)

The development of a reliable and accurate free-air thermometer is discussed.

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